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Photoprotons from nitrogen

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With 5 figures in the text

SUMMARY

The results of a study of the (γ, p) reaction in N^{14} are presented. A target of nitrogen gas at 1 atm pressure was used. The source of photons was the bremsstrahlung beam of a 30 Mev synchrotron. Irradiations were carried out at 11.5 and 15.5 Mev maximum bremsstrahlung energy. The protons were recorded by means of nuclear emulsions. Both irradiations gave proton spectra containing well-resolved peaks. By comparing the two proton spectra the peaks could be identified as resonances in N^{14}. The result has been compared with the inverse process and measurements of (γ, n) and (γ, p); the agreement was found to be quite satisfactory. The cross-section of the (γ, p) reaction up to 15 Mev is given.

Introduction

Through numerous experimental investigations the existence of the giant resonance in photonuclear reactions is well-known. It has also been found by irradiation of light nuclei with photons of energies below the giant resonance that nucleons are being ejected with distinct energies, indicating resonances in the photon absorption. Such fine structure has been observed, partly in (γ, n) processes, in which the neutron energies have been directly measured or breaks in the activation curve have been found, partly in (γ, p) reactions, in which the proton energies have been directly measured. Even in (γ, α) processes discrete energies of α-particles have been obtained. In this work the (γ, p) reaction in nitrogen has been investigated.

The purpose has primarily been to study the nature of the γ-absorption process below the giant resonance and at the same time to study the excited levels in the N^{14}-nucleus. Secondly, it has been our intention to compare the results with the inverse process, with (γ, n) measurements and earlier (γ, p) measurements. In the last-mentioned case different results were obtained, according as the protons were recorded in a cloud chamber or in nuclear emulsions. Thirdly, we have shown that it is possible by nuclear emulsions to study successfully protons even with as low energy as 1 Mev.

The present study is the second in a series of investigations, devoted to the light nuclei, being carried out in Lund. The first one concerned the photodisintegration of oxygen [1, 2].

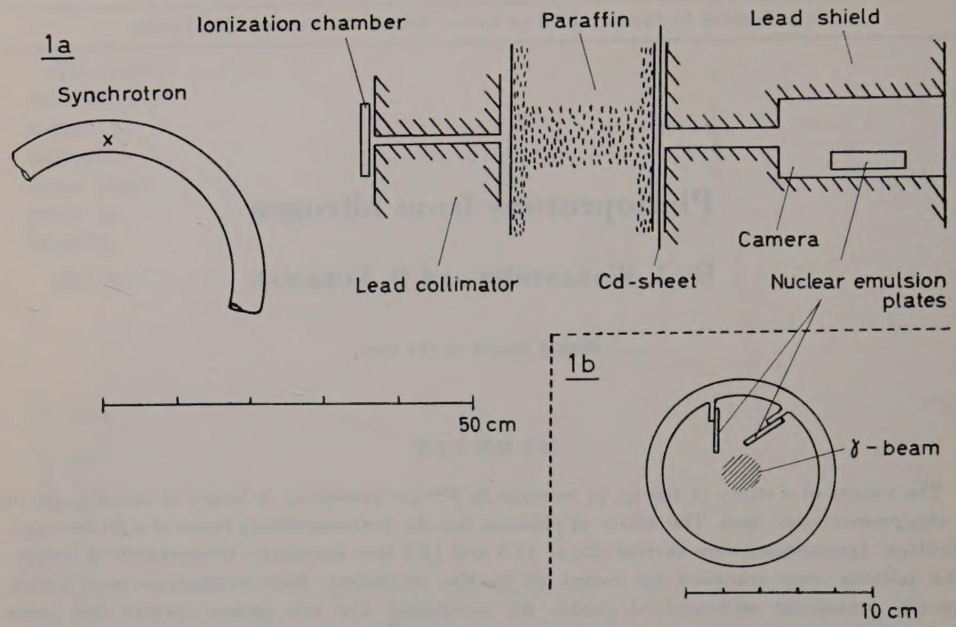

Fig. 1. Experimental arrangement. In Fig. 1*a* the arrangement is seen from above. Fig. 1*b* shows the camera in the direction of the γ-beam and the position of the nuclear plates.

Experimental arrangement

Exposure

The source of photons in this (γ, p) investigation was the 30 Mev synchrotron of the University of Lund. Irradiations were performed at the maximum bremsstrahlung energies 11.5 and 15.5 Mev. The energy scale of the synchrotron was calibrated at the thresholds of the reactions Cu^{63} (γ, n), O^{16} (γ, n), and C^{12} (γ, n). A nitrogen gas target of 1 atm pressure was used. The experimental arrangement is shown in Fig. 1*a*.

The γ-beam was collimated by a cylindrical lead collimator. The beam diameter was 2 cm in the gas chamber. A relatively large diameter was used in order to obtain reasonable irradiation times, since the intensity of the synchrotron beam was relatively low.

The camera was made of brass and its inside was covered with lead. It was well shielded by lead.

The intensity of the beam passing through the camera was monitored by a transmission ionization chamber calibrated against a Philips ionization chamber placed in the centre of a lucite cylinder with a diameter of 10 cm and a height of 10 cm. The total dose amounted to about 500 roentgens.

The photoprotons were recorded in Ilford C2 nuclear emulsions of 200 μ thickness. The plates were glued to two shelves in the camera (see Fig. 1*b*).

During the irradiation the camera was cooled with running water to keep the nuclear emulsions at a constant low temperature.

In the first irradiation it was found that the background was so strong that the fine structure in the proton spectrum could not be distinguished. The background arises chiefly from the exothermic reaction $N^{14}(n, p)C^{14}$. To suppress this background a 20 cm thick paraffin layer and a 0.13 cm thick cadmium sheet were placed between the collimator and the camera. The background was thus cut down considerably; but the γ-ray intensity was reduced by only 30 %.

Measurements

The nuclear emulsions were developed with an amidol developer. The shrinkage factor was determined and a value in agreement with Rotblat and Tai [3] was obtained. The microscope measurements were performed in a room with 65 % humidity.

In the plates irradiated in the main experiments the lengths of those tracks having a range of more than 10 μ and which could have come from the irradiated gas cylinder were measured. Also the angle between the horizontal projection of the track and the γ-beam was measured and the dip angle of the track in the plate was calculated from the length measurements. From these data the angle between the proton track and the γ-beam direction was calculated. The length of the proton track was calculated and the energy of the proton when striking the plate was obtained from the range-energy tables for protons recently published by Barkas [4].

In order to determine the energy of the proton at the ejection it is necessary to consider the energy loss in the nitrogen gas. Since the irradiated gas cylinder was fairly thick, the exact point of ejection could not be determined, but for each proton the most likely path length in the gas was calculated. The energy loss in the nitrogen gas was then obtained from Whaling's energy-range tables [5].

Background

The background events in the experiment may have the following origin:

1. Protons from (n, p) reactions in nitrogen. This process is exothermic with $Q = +0.63$ Mev, and so even thermal neutrons give rise to protons. We have, however, only measured protons, the energies of which are certainly of a higher value than the energies of those protons originating from thermal neutrons. On the other hand fast neutrons may give rise to background events. The fast neutrons originate mainly from the (γ, n) reaction in the lead collimators.
2. Protons originating in nuclear reactions in the walls of the camera. Through a special run with the camera evacuated, it was shown that this background effect can be entirely neglected.
3. Recoil protons ejected when fast neutrons collide with the hydrogen nuclei of the emulsion. Some of these protons pass through the surface of the emulsion and may therefore be confused with entering protons. In most cases they can be sorted out, as they do not have a characteristic track end, but as far as low-energy protons are concerned this separation is hard to perform.
4. Furthermore, α-tracks may be hard to separate from short proton-tracks. These α-tracks may originate from (n, α) and (γ, α) processes in nitrogen. On account of the low irradiation energies and the energy loss in nitrogen this background may be neglected. On the other hand α-tracks can be obtained from natural radioactive materials occurring as impurities.

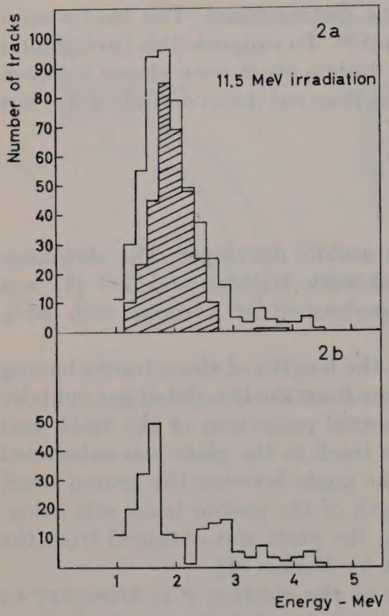

Fig. 2. The proton distribution from the 11.5 Mev irradiation. The energy scale gives the sum of the proton energy and the recoil energy of C^{13}. In Fig. 2*a* the background is shaded and in Fig. 2*b* the background is subtracted.

In order to investigate the background of fast neutrons special runs at the two irradiation energies were performed. For these runs the collimator was replaced by a blind collimator of the same shape, so that the γ-intensity in the camera was negligible. By doing this the number of neutrons was somewhat increased, but this effect can easily be calculated and corrected for. The background tracks were measured according the same selection rules as the tracks on the main plates. In this way the background at proton energies larger than 2 MeV was determined. At lower energies the background consists of tracks from recoil protons and α-particles. The background from α-particles, especially, may vary from plate to plate. In order to determine the background at energies lower than 2 Mev, tracks directed against the beam were also measured. These tracks were dealt with as if they had come from the beam. If we assume that the background below 2 Mev is isotropic, these measurements should give us the true background. The assumption that the background is isotropic was verified by measurements on the background plates.

Results

The photoprotons from the main irradiations group themselves around discrete energy values. In order to obtain a good resolution tracks considered uncertain have been excluded. These are all tracks with a dip angle in the emulsion greater than 40°; such tracks lead to erroneous results when the grains in the tracks approach each other so that they touch. Further all tracks having an inclination to the beam of less than 30° have been excluded, since the correction for the energy loss in nitrogen becomes too uncertain. The energy distribution of the photoprotons from the two main irradiations, after the above-mentioned elimination, is shown in Figs. 2*a* and

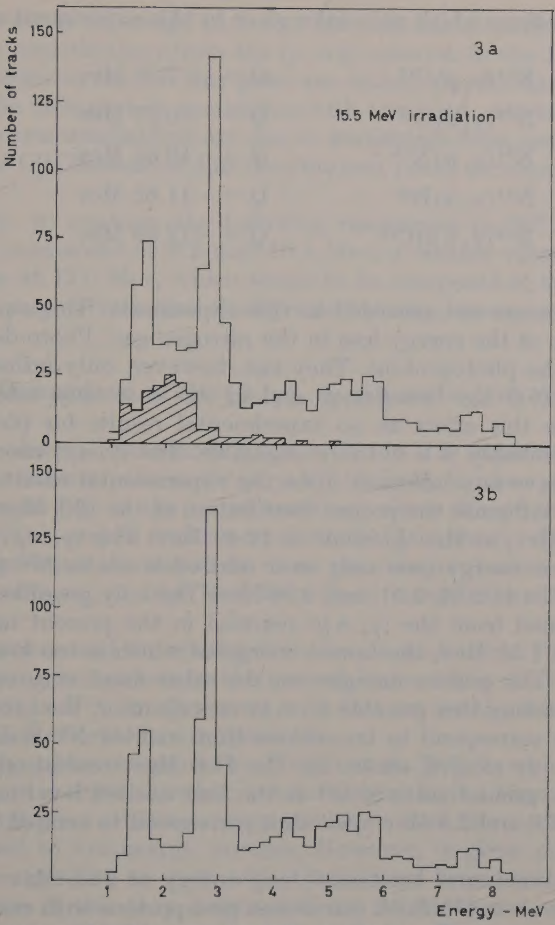

Fig. 3. The proton distribution from the 15.5 Mev irradiation. The energy-scale gives the sum of the proton energy and the recoil energy of C^{13}. In Fig. 3*a* the background is shaded and in Fig. 3*b* the background is subtracted.

3*a*. The energy scale in these figures give the energy of the proton plus the recoil of the carbon nucleus. The background is also shown in the figures. Figs. 2*b* and 3*b* show the energy distribution after the background has been subtracted.

Both energy spectra show well-resolved peaks. In Fig. 2*b*, corresponding to 11.5 Mev maximum bremsstrahlung energy, peaks are thus observed at 1.6 and 2.8 Mev. In Fig. 3*b*, corresponding to 15.5 Mev maximum bremsstrahlung energy, the same peaks are observed, here at 1.6 and 2.9 Mev. In addition, we have observed a lower peak at 4.3 Mev as well as a wide peak at 5.4 Mev, which might be resolved into two peaks. Finally, there also exists a peak at 7.6 Mev.

The experimental width of the energy peaks depends on the thickness of the gas target, the inaccuracy of the length measurements, and the straggling of the proton track. These errors have been estimated and give a total standard deviation of 0.15 Mev for a 2 Mev proton.

Those nuclear reactions which may take place in this experiment are:

$N^{14}(\gamma, p)C^{13}$ $Q = -\ 7.55$ Mev
$N^{14}(\gamma, d)C^{12}$ $Q = -10.27$ Mev
$N^{14}(\gamma, n)N^{13}$ $Q = -10.55$ Mev
$N^{14}(\gamma, \alpha)B^{10}$ $Q = -11.62$ Mev
$N^{14}(\gamma, np)C^{12}$ $Q = -12.49$ Mev.

The photoneutrons are not recorded in this experiment. The α-particles are not recorded on account of the energy loss in the nitrogen gas. Photo-deuterons cannot be separated from the photoprotons. They can, however, only influence the proton distribution of the 15.5 Mev irradiation and in this case only below 3 Mev. It is difficult to estimate this effect as no experimental results for photodeuterons in light nuclei exist. Probably it is entirely negligible. The (γ, np) reaction is thus the only one that can have any influence upon the experimental result. Like the (γ, d) reaction it can only influence the proton distribution at the 15.5 Mev irradiation and then only below 3 Mev, as the threshold is 12.49 Mev. The (γ, np) reaction can at the actual irradiation energy pass only over excited levels in N^{13} to C^{12}. The first excited levels in N^{13} lie at 2.37, 3.51, and 3.56 Mev. The only possible proton energies, which can be obtained from the (γ, np) reaction in the present investigation, are thus 0.39, 1.46, and 1.51 Mev, the lowest energy of which is too low to be recorded in this experiment. The greater energies on the other hand may contribute to the 1.6 Mev peak. Neglecting this possible (γ, np) contribution, the proton distribution obtained must thus correspond to transitions from excited N^{14} nuclei to C^{13} nuclei in the ground state or excited states. At the 11.5 Mev irradiation the transitions must go only to the ground state of C^{13} as the first excited level in C^{13} lies at 3.09 Mev. The peaks at 1.6 and 2.8 Mev must thus correspond to excited levels at 9.2 and 10.4 Mev in N^{14}.

When using the maximum bremsstrahlung energy of 15.5 Mev, transitions can also go to excited levels in C^{13}. Such transitions give protons with energies lower than 5.0 Mev. The peaks at 1.6 Mev and 2.9 Mev correspond of course to ground-state transitions, as they have already been observed in the 11.5 Mev irradiation. It is, however, possible that in these peaks there are also protons, which are due to transitions to excited levels in C^{13}. It is to be expected that in those cases, where the transitions to excited levels in C^{13} exist, corresponding ground state transitions should be observed. Since no discernible peaks in the energy range 6–7 Mev have been obtained in Fig. 3*b*, we conclude that there are no strong transitions to excited levels in C^{13}. The only level in N^{14} which could contribute to the 2.9 Mev peak would be the higher of the two unresolved levels in the wide resonance at 13.0 Mev. If this contribution is of importance it would immediately show up as a skewness in the observed 2.9 Mev peak. Such a skewness does not exist. On the contrary the observed width of the peak is the same as the width that has been estimated from the experimental broadening of a sharp level.

It is more difficult to say whether all protons in the 1.6 Mev peak are due to transitions to the ground state in C^{13}. Some of the protons in this peak may be due to transitions from resonances in the range 12.2–13.0 Mev to the three lowest excited levels in C^{13}. In Fig. 3*b* it appears from the peaks in the range 4.7–5.5 Mev that we are exciting levels in the range 12.2–13.0 Mev. As has already been mentioned there may also exist contributions from the (γ, np) reaction in the 1.6 Mev peak. In spite of this the protons in the 1.6 Mev peak are mainly due to transitions to the ground state, as will be discussed in connection with the yield. According to the above the protons in the two irradiations are due to transitions from resonances in N^{14} to the ground state of C^{13}. Because of this the obtained peaks correspond directly to excited levels in N^{14}.

From the (γ, p) reaction the following resonances in N^{14} have been observed: strong, sharp resonances at 9.2 and 10.4 Mev; a weaker resonance at 11.8 Mev; a wide resonance at 13.0 Mev, which seems to be composed of two resonances at 12.6 and 13.2 Mev, respectively; and finally a new strong resonance at 15.2 Mev.

Comparison of the (p, γ), (γ, p), and (γ, n) reactions

Most of the observed resonance levels in N^{14} in this experiment have earlier been observed in the inverse process $C^{13}(p, \gamma)N^{14}$ [6, 7, 8], in absorption measurements of γ-rays in nitrogen [9], in the (γ, p) reaction, where the protons are recorded in a cloud chamber [10] and in nuclear emulsions [11], in the (γ, n) reaction [12, 13, 14].

In (p, γ) experiments it has so far been possible to observe N^{14} levels only up to 10.4 Mev. Results up to 10.4 Mev have been compiled by Ajzenberg-Selove and Lauritzen [16].

The cross-sections and the widths of the levels are known. The 9.18 and 10.43 Mev levels have strong transitions to the ground state, while the 9.50 Mev level decays to excited levels in N^{14}. In agreement with this we see the 9.2 and 10.4 Mev levels, whereas the 9.5 Mev level is not observed.

Nor does a (γ, p) investigation by Wright *et al.* [10], in which they measured the proton lengths in a cloud chamber, reach energies higher than 10.4 Mev. The cloud-chamber method gives a better energy resolution than the nuclear emulsion method, but is restricted to low-energy protons. However, it gives poor statistics. Wrigth *et al.* have therefore had to work with a maximum bremsstrahlung energy of up to 23 Mev. In spite of this they determined the 2.9 Mev peak with only nine tracks. They obtained a remarkably good agreement with above-mentioned (p, γ) measurements, not only as concerns the position of the energy levels but also as concerns the integrated cross-sections, if detailed balance is assumed. This indicated that the photoprotons in the 9.2 and 10.4 Mev peaks all correspond to ground-state transitions.

An investigation of (γ, p) reactions has earlier been made by Spicer [11]. He has used the same technique used in the present study. However, Spicer's results diverge considerably from ours. He has not obtained any fine structure in his proton distribution. The maximum of his proton distribution lies at a proton energy of 2.1 Mev —that is, in an energy range in which we have observed only a few protons. In Fig. 2*a*, however, it is observed that in our investigation the background has a peak at this very energy. Possibly Spicer has not completely corrected for the background protons.

Chidley and Katz [12] have, when studying the (γ, n) reaction, observed levels at 11.5 and 12.7 Mev. The former level has a width of 0.3 Mev, the latter a width of 1 Mev. They have also observed a level at 10.8 Mev, immediately above the threshold of the reaction. The two higher levels can be identified in our proton distribution.

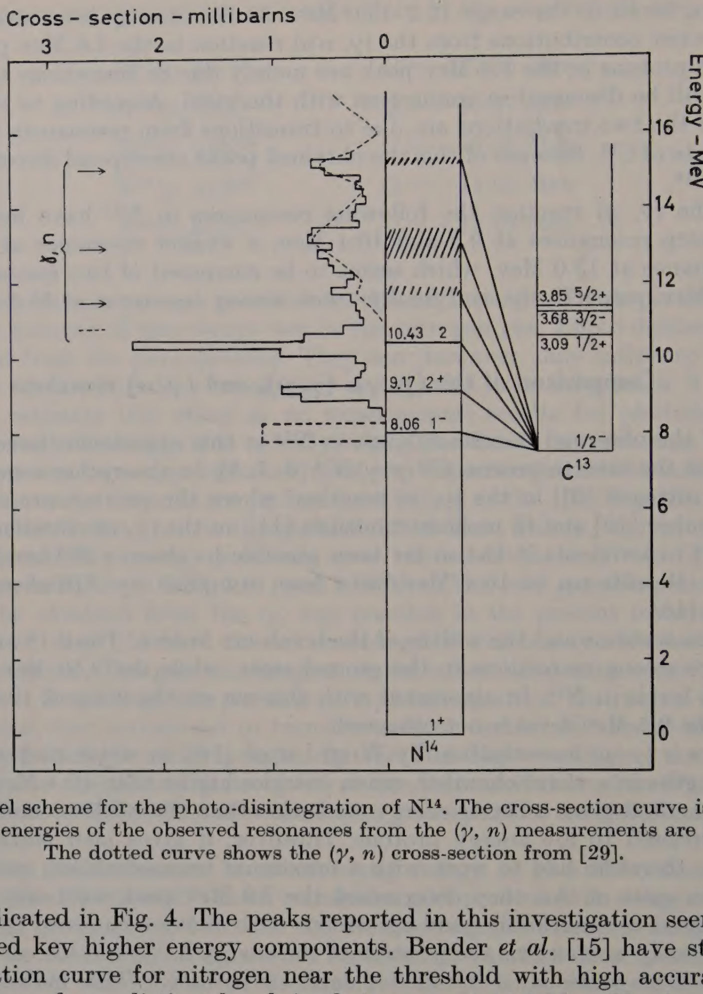

Fig. 4. The level scheme for the photo-disintegration of N^{14}. The cross-section curve is plotted to the left. The energies of the observed resonances from the (γ, n) measurements are indicated. The dotted curve shows the (γ, n) cross-section from [29].

They are indicated in Fig. 4. The peaks reported in this investigation seem to have some hundred kev higher energy components. Bender *et al.* [15] have studied the (γ, n) activation curve for nitrogen near the threshold with high accuracy. They have not observed any distinct break in their curve at 10.8 Mev. Nor have we been able to observe any resonance at 10.8 Mev in our investigation.

Quite recently Bertozzi *et al.* [13] have studied the photoneutron spectrum from nitrogen by means of the time-of-flight technique. Their results are still preliminary but promising. They have observed strong ground-state transitions at 13.0 and 15.1 Mev. This is in good agreement with our observations.

Recently new results from the (γ, n) measurements have been obtained in Saskatchewan [14]. These also give strong resonances in nitrogen at about 13 and 15 Mev.

The yield

After the distribution in Fig. 3*b* has been corrected for the shape of the bremsstrahlung spectrum it is possible to compare the strength of the observed N^{14} resonances.

Our investigation is not suitable for an absolute determination of the yield. An absolute scale of the cross-section can, however, be calculated, if we compare the number of protons in the 10.4 Mev peak with the cross-section of the inverse process (p, γ) reported by Willard *et al.* [8]. We have taken into consideration the fact that only 90 % of the photons go to the ground state in this process. In this calculation detailed balance has been assumed.

A calculation of the cross-section of the (γ, p) reactions in N^{14} up to 15 Mev has been made from our measurements and is shown in Fig. 4. It is assumed in this calculation that all protons correspond to transitions to the ground state of C^{13}. That this is true for the 10.4 Mev resonance has already been shown. Owing to the width of the γ-beam in our experiment part of the low-energy 1.5 Mev protons will lose so much energy in the nitrogen gas that the track lengths in the emulsions become too short to be measured. This effect has been calculated to 20 %. The 9.2 Mev resonance has been corrected for this effect in Fig. 4, and the integrated cross-section of the resonance has been determined to 0.43 millibarn-Mev. Hanna and Meyer-Schützmeister [9] have, by γ-absorption for the same level, determined the following values for the level width and the cross-section: $\Gamma = 77 \pm 12$ ev and $\sigma_r = 5.5 \pm 1.8$ barn. From this the integrated cross-section can be calculated to be 0.66 ± 0.12 millibarn-Mev. The agreement between the values obtained by Hanna and Meyer-Schützmeister and the authors shows that all protons in the 9.18 Mev peak correspond to transitions to the ground state of C^{13}. In Fig. 4 is also shown the integrated cross-section of the 8.06 level, calculated from the inverse process [17]. The protons from this level are of too low an energy to be recorded in our experiment.

The size of the (γ, np) cross-section can be obtained by comparing the (γ, n) measurements of Johns *et al.* [18], made by radioactivity methods, with the $(\gamma, np) + (\gamma, n)$ measurements of Ferguson *et al.* [19], made with a neutron detector. The difference in their results is $\sigma(\gamma, np)$. This shows that the (γ, np) reaction starts to be noticeable at 15 Mev. It is thus convenient to use, as we did, a maximum bremsstrahlung energy of about 15 Mev.

The integrated cross-section of the (γ, p) reaction, from the threshold up to 15 Mev, can be calculated from Fig. 4 to be 3.5 millibarn-Mev.

It is difficult to compare the integrated cross-section of the two observed peaks in Fig. 2*b*. The maximum bremsstrahlung energy was so close to the 10.4 Mev resonance that a slight drift in the energy of the synchrotron may cause large errors in the yield.

The γ-absorption

The giant resonance in photonuclear reactions is caused by electric dipole absorption. The integrated cross-section of the resonance is predicted by the sum rules for electric dipole absorption [20]. Below the giant resonance, however, the electric dipole absorption is pressed down due to the correlation between the proton and the neutron motions. Blatt and Weisskopf [21] predict from this that the photonuclear absorption is largely of an electric dipole nature only above 15 Mev. Between the threshold and 15 Mev the absorption should be due to magnetic dipole and electric quadrupole transitions. It is thus of great interest to study the nature of the γ-absorption in this range.

The 8.06, 9.17, and 10.43 Mev levels have been carefully studied in the (p, γ) reaction. The angular distributions [6, 8, 22] and the integrated cross-section give

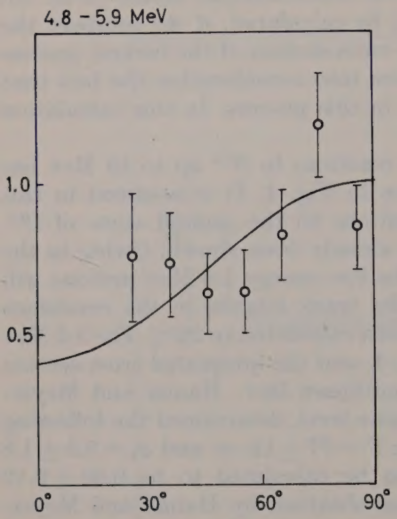

Fig. 5. The angular distribution of the protons from the energy interval 4.8–5.9 Mev.

information on the spin and parity of the levels. Thus the 8.06 Mev level has been found to have 1^-. The 9.17 and 10.43 Mev levels have been regarded as 2^- levels on account of their large γ-widths. Polarization measurements on photons from the 9.17 Mev level, by the use of deuterium soaked nuclear emulsion, have recently been carried out by Strassenburg *et al.* [23]. These measurements are in agreement with those expected from a combination of M 1 and E 2 transitions, but do not agree with E 1. Rose *et al.* [24] have assigned the level to $J=2$ by angular correlation and distribution measurements. The level is thus now thought to be 2^+.

The angular distribution of the protons in the $C^{13}(p, p)C^{13}$ reaction has recently shown that the 10.43 Mev level also has even parity. Willard *et al.* [8] have obtained the angular distribution of $1–0.5 \cos^2\theta$ for the protons from the 10.43 Mev level to the ground state. This angular distribution indicates a spin of 2^- or 2^+. Therefore also this level now is thought to be 2^+.

We have measured the angular distribution of the photoprotons corresponding to the energy interval 12.4–13.5 Mev. After a solid angle correction of $\sin\theta$ the distribution is shown in Fig. 5. The result is $1-(0.6\pm0.1)\cos^2\theta$. From the lower levels the distributions are so uncertain that no definite conclusions can be made. These distributions are already known with good accuracy from the (p, γ) measurements.

From the integrated cross-section of the wide 13.0 Mev resonance $(2J+1)\Gamma_{\text{rad}}$ has been calculated to be 65 ev, assuming that the peak corresponds to two levels. Even with $J=2$ the Γ_{rad}-width is so large that the E 1 transition should be expected before the M 1 transition.

In N^{14} many levels above 10.4 Mev are known from different reactions. For some of these spin, parity and isobaric spin are also known [16]. None of these known levels can be excited by M 1 absorption. The only one of them that can be excited by E 1 absorption is a level at 13.2 Mev, which is determined to be 0^- or 1^- by the $C^{12}(d, n)N^{13}$ reaction [27]. Our level at 13.0 Mev may correspond to this level. Our angular distribution, however, suggests a 2^- level. In any case E 1 absorption is likely present at this energy. E 1 as well as M 1 and E 2 absorption have thus been observed in the range below 15 Mev. Even if only the 9.17 and 10.43 Mev levels have an even parity, this means that 40 % of the total γ-absorption below 15 Mev is of a magnetic dipole and electric quadrupole nature. Blatt and Weisskopf's prediction that the E 1 absorption is strongly suppressed in this range is thus valid for the N^{14} nucleus.

The largest part of the γ-absorption in this energy range occurs through discrete resonances of the N^{14} nucleus as is shown in Fig. 4. This has also been observed in O^{16} [1].

Conclusion

This experiment gives the following results:

1 a) The levels at 9.17 and 10.43 Mev in the N^{14} nucleus, which are known from the $C^{13}(p, \gamma)N^{14}$ reaction and which have strong γ-transitions to the ground state, have been observed in the (γ, p) process.

1 b) Levels in N^{14} nucleus have been observed at 11.8, 13.0 and 15.2 Mev. These can be identified with levels reported from (γ, n) reactions.

1 c) The angular distribution of the photoprotons corresponding to the energy interval 12.4–13.5 Mev has been measured with the result

$$W(\theta)_{13.0} = 1 - (0.6 \pm 0.1)\cos^2\theta.$$

2 a) A calculation of the (γ, p) cross-section from the threshold up to 15 Mev has been made. The absolute scale of the cross-section has been obtained by comparison with the inverse process. The ratio between the integrated cross-sections of the strongest peaks agrees with earlier measurements.

2 b) The (γ, p) absorption in N^{14} below 15 Mev amounts to 3.5 millibarn-Mev. The absorption occurs mainly through sharp levels of the N^{14} nucleus.

2 c) At least 40 % of the total γ-absorption in N^{14} is due to M 1 and E 2 absorption.

A report on a part of the present investigation was given at the Amsterdam Nuclear Conference (1956) [28].

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Note added in proof. — A recent investigation by King et al. [29] has just come to our attention, in which the N^{14} (γ, n) cross-section has been determined by measuring the activation curve. Their result has been indicated by a dotted line in Fig. 4. It shows a very good agreement with our (γ, p) cross-section. Gell-Mann and Telegdi [30] predict that the (γ, n) and the (γ, p) cross-sections must be for each individual state identical with each other as a function of energy and angle if charge independence is rigorously true. It has been shown for oxygen [2] that the hypothesis of charge independence is fulfilled within the limits of the experimental errors. The same result has now been obtained for nitrogen. The good agreement between the (γ, p) and (γ, n) cross-sections is proof of the validity of the principle of the detailed balance since the absolute scale for the (γ, p) cross-section is estimated according to this principle.

Two Japanese papers dealing with the photodisintegration of nitrogen have also been published during the last months. The first one is a theoretical work by Fujii [31], who calculates the integrated cross-section of the pygmo-resonance in the energy range 10–15 Mev. Fujii predicts that this resonance arises, when the more loosely bound nucleons outside the core are excited. The photon absorption is presumed to be electric dipole in character. Concerning nitrogen the two extra nucleons are characterized by $p^1/_2$ and one of them is thus excited to $d_{3/2}$. The integrated cross-section, 20.9 millibarn-Mev, is determined from Fujii's values for the width and peak of the resonance. This value should be compared with our corresponding value, which for the (γ, p) absorption below 15 Mev in N^{14} amounts to 3.5 millibarn-Mev. Only 60 % of this absorption are due to E1 absorption. Even if Fujii's value ought to be divided by two [32], it is considerably higher than the experimental value. The fine structure both in the (γ, p) and the (γ, n) reactions cannot be explained according to this theory. Fujii's model also predicts the angular distribution of the emitted photonucleons. On transition from $p^1/_2$ to $d_{3/2}$ it will be $1 + 1.5 \sin^2\theta$, which is in agreement with our angle distribution from the energy range 12.4–13.5 Mev in nitrogen.

The second Japanese work is an experimental investigation of breaks in the $N^{14}(\gamma, n)N^{13}$ activation curve [33]. A number of breaks have been observed. Most of them can be identified with the peaks in the energy spectrum of photoprotons, which we have received in our investigation. This confirms further the agreement between the (γ, n) and the (γ, p) process.

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